Performance Enhancement of an Air Conditioner with Condensate Mist Cooled Condenser

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ABSTRACT

This paper presents a simple and efficient methodology to design a household (and can also be used for commercial air conditioning purposes) air conditioner, predicts the performance of air conditioning unit and how the thermal performance can be improved, when the water mist system is coupled with the air cooled conditioner as a pre-cool for condenser inlet air to increase the cooling capacity, and decrease the compressor power consumption. Inputs for formulation include inlet air DBT and humidity ratio, air velocity, water temperature and flow rate, and geometrical properties of evaporative medium. Generally air conditioning units are used for small and medium scale residential buildings and the large units are used for the commercial purposes. Therefore, more energy efficiency and lower cost are needed along with reliable control for the air conditioning units. The influence of condenser and evaporator inlet air temperatures on the cooling capacity and power consumption has been investigated and presented. It has been found that due to the coupling of water mist with air cooled condenser, the cooling capacity of the air-cooled,air conditioner can be increased up to 17.5%, and the compressor power consumption can be reduced up to 15.5%. Thus, it is concluded that the application of water mist condenser, inlet air pre-cooling could increase the COP by up to 37%, especially when the ambient relative humidity is low[10].

KEYWORDS: *Thermal performance, water mist, air cooled condenser, air conditioner, simulation program.*

I. Introduction

Refrigeration is the cooling effect of the process of extracting heat from a lower temperature heat source, a substance or cooling medium and transferring it to a higher temperature heat sink, probably atmospheric air, or water, to maintain the temperature of the heat source below that of the surroundings. The most common refrigeration systems are vapor compression systems. The use of water mist in decreasing the air temperature entering the condenser will definitely increase the efficiency of heat exchange at the condenser and so increase efficiency of the condenser and the coefficient of performance (COP) of the air conditioning unit (ASHRAE, 2009 [1,2])

II. Literature Review

Water-spray mist cooling system is used to assess its performance, which is based on the pre-cooling air entering the condensers to decrease compressor power consumption of air-cooled chillers with a nominal capacity of 600 kW. It mainly consists of atomization nozzles, water pipe work, a filter assembly, mounting brackets and a high pressure pump with around 70 bars of pressure. Based on the experimental data obtained from the measurements under ambient temperatures ranging from 25℃ to 39℃, the reduction in air temperature were 5 to 20℃. The energy efficiency ratio (EER) increased by a 13.5%, while an increase of 5.9% in the cooling capacity was obtained [3]

It is possible to improve the energy efficiency of air-cooled condensers by installing water mist system to pre-cool the outdoor air before entering

condensers. The water mist pre-cooling system is not a new concept, and has been applied successfully in the industries [5].

The chiller performance can be improved by using water mist to pre-cool ambient air entering the condensers to decrease compressor power. A simulation analysis on an air-cooled chiller equipped with a water mist pre-cooling system under head pressure control shows that applying water mist pre cooling enables the coefficient of performance (COP) to increase. They concluded that the application of water mist pre-cooling could increase the COP in various degrees by up to 30%, especially when the relative humidity is low. Furthermore incase of using a water mist system, the chiller power could reduce by 16.2% or 15.8% [6].

However, the application of water-mist system associated with a chiller system is not common, and a limited number of studies are found on the performance of chillers with water mist system.

III. Theoretical Analysis

When the water mist system is coupled with the air conditioner, the temperature of the air at the inlet of the air-cooled condenser will decrease compared the temperature of the ambient air, as well the condensing temperature and condensing pressure will decrease accordingly, as shown in Figure (1).

The refrigeration cycle of the air conditioner with water mist system is changed from the cycle 1-2-3-4-1 to 1'-2'-3'-4'-1'. As the condensing pressure decreases, the work of the compressor will also decrease. However, the cooling capacity may be increase, so the COP of the chiller system will increase. Theoretically, air-cooled condenser coupled with a water mist system will improve the air conditioner efficiency, but it will depend on the ambient climatic conditions, cooling load, etc.

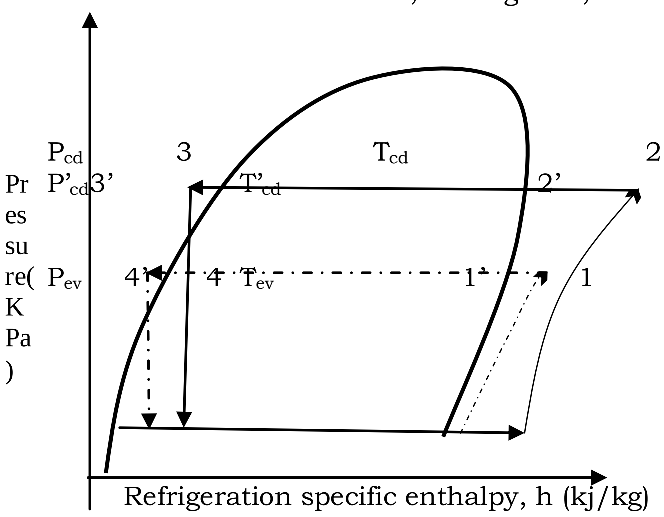

Fig [1]. Vapour compression refrigeration cycle.

IV. Mathematical Formulation

A. Air Conditioner with air cooled condenser

The measured operating data for the air-cooled air conditioner included the power of compressor, W_{CP}; the power of refrigeration cycle, W_{RP}, which equal to the power of compressor plus the power of fan, cooled air supply temperature, $T_{ea,s}$, cooled air return temperature, T_{ea},r; evaporating temperature, T_{ev} and condensing temperature, T_{cd} of refrigeration cycle. The cooling capacity of the air conditioner, Q_E is:

$$Q_E = m_a.(h_{ea,r} - h_{ea,s}) \quad \dots (1)$$

Where ma is the cooled air mass flow rate, C_a is the specific heat capacity of air, Where: $h_{ea,r}$, $h_{ea,s}$ are enthalpies of the air at evaporator inlet and outlet, respectively (kJ/kg).

Heat rejection, Q_R was calculated by Eq. (2). The heat rejection airflow, V_a was determined by Eq. (3), where $T_{ca,l}$ is the temperature of air leaving the condenser.

$$Q_R = Q_E + W_{CP} \quad \dots (2)$$

$$V_a = Q_R/(\rho_a C_a\ (T_{ca,1} - T_{ca,e})) \quad \dots (3)$$

The air conditioner COP is expressed as cooling capacity, Q_E over power consumption W_{CP}, as follow:

$$COP = Q_E/\ W_{CP} \quad \dots (4)$$

For any given cooling capacity, Q_E, compressor power, W_{CP} and heat rejection, Q_R will vary according to the condensing temperature, T_{cd}.[10]

B. Air Conditioner with water Mist

While the water mist system operates,(with reference to fig. 1)

$$W_{\text{air cooling}} = P_1 V_1 \frac{n}{n-1}\left[\left(\frac{P_2}{P_1}\right)^{\frac{n-1}{n}} - 1\right]$$

$$W_{\text{water cooling}} = P_1 V_1 \frac{n}{n-1}\left[\left(\frac{P_2''}{P_1}\right)^{\frac{n-1}{n}} - 1\right]$$

$$\%\ \text{saving} = \frac{W_{air} - W_{water}}{W_{air}}$$

$$= \frac{\left[\left(\frac{P_2}{P_1}\right)^{\frac{n-1}{n}} - 1\right] - \left[\left(\frac{P_2''}{P_1}\right)^{\frac{n-1}{n}} - 1\right]}{\left[\left(\frac{P_2}{P_1}\right)^{\frac{n-1}{n}} - 1\right]}$$

$$=\left[1-\frac{\left[\left(\frac{P_2''}{P_1}\right)^{\frac{n-1}{n}}-1\right]}{\left[\left(\frac{P_2}{P_1}\right)^{\frac{n-1}{n}}-1\right]}\right]*100\%$$

In terms of temperature at compressor outlet

$$\%\ \text{saving}=\left[1-\left(\frac{\frac{T_2''}{T_1}-1}{\frac{T_2}{T_1}-1}\right)\right]*100$$

$$=\left[1-\left(\frac{T_2''-T_1}{T_2-T_1}\right)\right]*100$$

Work required by condenser fan (air-side)

$$W_{f,comp}=\frac{V_a \Delta P_a A_f}{\eta_f}$$

Where,

V_a= velocity of air,

ΔP_a= Pressure drop,

A_f= Frontal area,

η_f=Fan efficiency.

As of now evaporators are not considered as the part of the study but we will wor on the optimisation of the tube thickness of the evaporator.

$$\text{C.O.P.}=\frac{Q_E}{W_{comp}+W_{condenser\ \ fan}+W_{evaporatoe\ \ fan}+W_{pump}}$$

(As the pump work is negligible so, by ignoring the pump work, we have,

$$\text{C.O.P.}=\frac{Q_E}{W_{comp}+W_{condenser\ \ fan}+W_{evaporatoe\ \ fan}}$$

$$\text{Seasonal C.O.P.}=\frac{\sum Q_E\,[t]}{\sum W[t]}$$

V. Results and Discussions

The condenser inlet air temperature affects the performance of the refrigeration cycle of air conditioner. As, mentioned, the decrease of condenser inlet air temperature, which will definitely decrease in condensing temperature, consequently the condensing pressure of the cycle was decreased. The use of water mist in decreasing the air temperature entering the condenser will definitely decrease the condensing temperature of the refrigeration cycle. As the condensing pressure decreases the power required by the compressor is also decreases and the further subcooling of the liquid refrigerant result in the huge saving of power consumption, increases the life of the components of an air conditioning unit.

VI. Conclusion

In the present research paper, the potential of applying mist pre-cooling have been investigated for air-cooled air conditioners. The cooling effect will be better and energy savings from water mist pre-cooling would be more significant if the air conditioner operate in a hot and arid outdoor environment. The theoretical study gave an idea on how the water mist system can be used as an evaporative pre-cooler to improve the efficiency under different weather and cooling load conditions. So, it can be concluded that: - The power consumption of the compressor was decreased and the cooling capacity was increased. As the temperature of air entering the condenser decreases, the COP of the air conditioner was increases.

Nomenclature

Symbol Definitions Units

C_a specific heat of air kJ/kg °C

henthalpykJ/kg

m mass flow rate kg/s

T temperature °C

Q_E cooling capacity kw

Q_R heat rejection kw

V_a volume rate of air m³/s

Wcompressor work kw

P density kg/m3

Subscripts

a air

db dry bulb

ea,r return air to evaporator

ea,s supply air from evaporator

ca,e entering air to condenser

ca,l leaving air from condenser

cd condensing

ev evaporation

mist water mist

Abbreviations

COP coefficient of performance

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